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FORECASTING AIDS FOR SETTING TROPICAL CYCLONE CONDITIONS: SASEBO AND IWAKUNI, JAPAN

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Forecast aids for predicting winds associated with tropical cyclones at Sasebo and Iwakuni, Japan, are developed. This report is divided into two parts: the first contains charts that relate winds observed at Sasebo and Iwakuni to tropical cyclone center winds as a function of storm location; and the second provides diagrams that estimate the worst case arrival time of winds of at least 50 kt.

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SECTION 1

INTRODUCTION

This report documents the development of forecast aids for predicting tropical cyclone associated winds at Sasebo and Iwakuni, Japan. The aids are of two forms:

- o charts which relate winds observed at the two stations to tropical cyclone center winds as a function of cyclone location.
- o diagrams which estimate the worst case (soonest) arrival time of winds of at least 50 kt.

The report is organized in four sections as follows.

Section 1, an introductory section, provides background information describing the techniques used and the normal results. References will be cited in this section to substantiate the validity of the basic methodologies. Sample charts and diagrams are presented and examples of their use are illustrated.

Section 2 and 3 are site specific to Sasebo and Iwakuni. These sections discuss unique considerations when applying the methodologies to these sites. Prime considerations unique to each location are data availability and limitations, data augmentation, general terrain features and the success of the development.

Actual charts and diagrams are presented for each site and their use is demonstrated.

Finally, section four summarizes the unique results and findings as well as implications to other sites and regions.

1.1 Forecast Aids

The forecast aids are of two general forms. The first is a map with contours of wind ratios (see Figure 1). These are ratios of winds observed at the object station to the maximum winds near the center of a tropical cyclone. Because these contours are determined by direction and distance from the station, within limits imposed by terrain exposure, the diagrams are referred to as terrain influence maps. Use of these terrain influence maps will be discussed in section 1.1.1.3.

The second form of forecast aid is a CHARM clock. The acronym CHARM is for an acceptable risk model (Cyclone/Hurricane Acceptable Risk Model). The CHARM clock, given wind probabilities based on the most recent forecast, estimates the worst case arrival time for 50 kt winds. Thus, the CHARM clock is an aid to tropical cyclone condition setting.

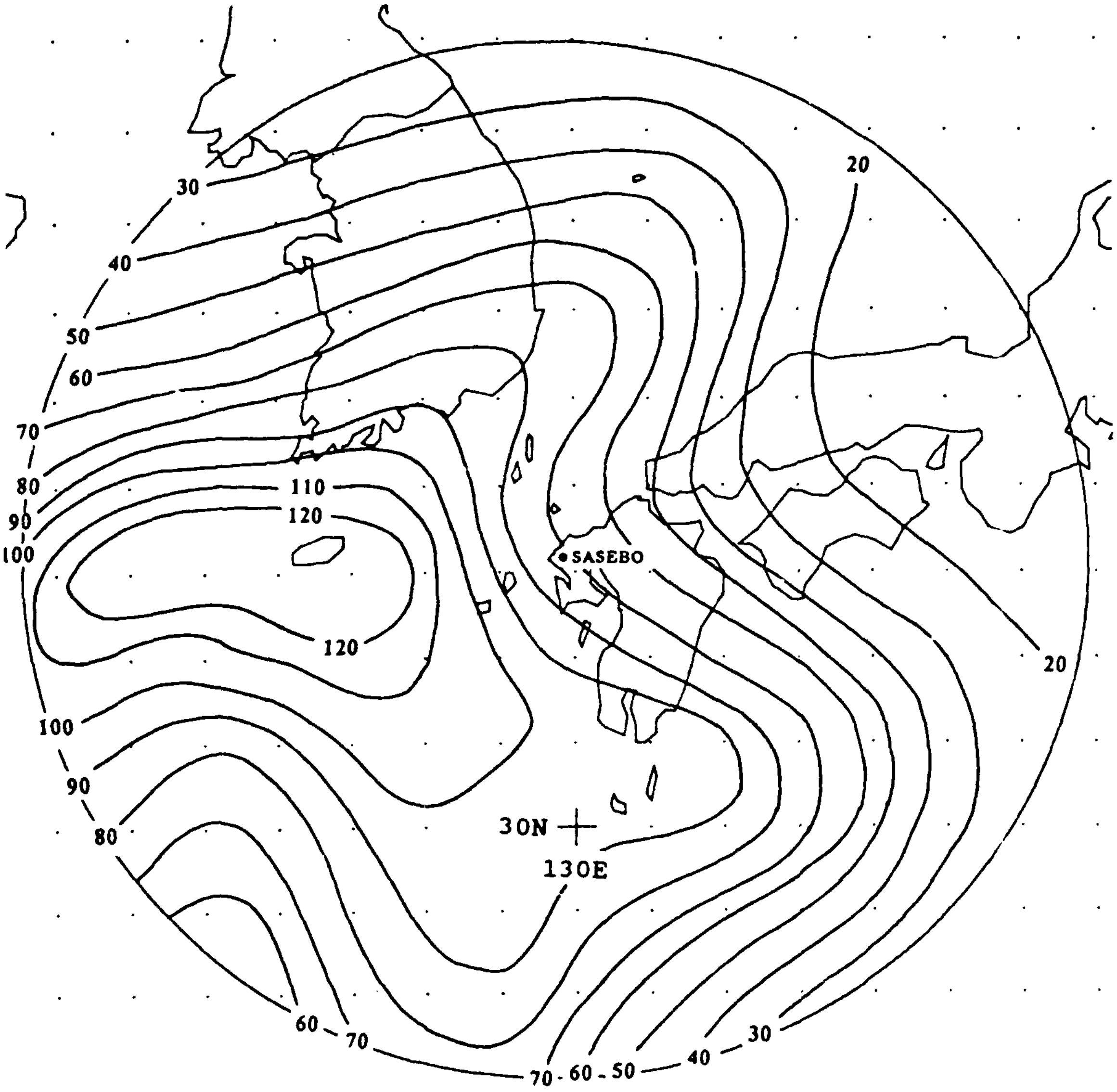

Figure 1. Maximum Gust Ratios (labelled as percentage) for Sasebo when a tropical cyclone of less than typhoon strength (<64 kt) is centered within 360 nm of the station. Locate the tropical cyclone center by latitude and longitude and interpolate the ratio (percentage) value. Multiply the tropical cyclone center wind speed by this percentage to get the wind speed value of the maximum gust expected with the given center position and wind speed. Multiply the maximum gust speed by 0.67 to find the maximum one-minute average sustained wind speed.

1.1.1 Terrain Influence Maps

1.1.1.1 Background for Terrain Adjustment

Forecasting wind conditions at a station during the passage of a tropical cyclone is a critical operational problem. The Air Force produced forecasts aids for several of their western Pacific bases which predict mean and maximum peak gusts for periods when a typhoon is within 360 nm of a base (Pettett, 1980). The need for similar forecast aids for Navy sites was recognized and the Naval Environmental Prediction Research Facility (NEPRF), Monterey, California was requested to produce the aids. NEPRF conducted the research and development involved in producing forecast aids. Aids have been developed for:

- Cubi Point, Philippines
  (Jarrell and Englebretson, 1982a)
- Yokosuka, Japan,
  (Jarrell and Englebretson, 1982b)
- Agana, Guam
- Hong Kong
- Kadena, Okinawa and,
- Misawa, Japan
  (Jarrell and Sanders, 1983).

This information is also used to adjust wind probabilities for terrain influence. Jarrell (1982) provides a description

of the use of this information to determine "terrain adjusted" wind probabilities and also provides a sample wind probability message.

1.1.1.2 Production of Terrain Influence Maps

The terrain influence maps are based on available surface wind observations at each site. Length of record and data limitations are discussed in Sections 2 and 3. Best track data for the tropical cyclones were extracted from Joint Typhoon Warning Center (JTWC) records for the periods when a tropical cyclone was within 360 nm of the station of interest. Aviation hourly observations at one- or three-hour intervals (as available), obtained from the National Climatic Data Center (NCDC), Asheville, NC, were extracted for the periods identified as having a tropical cyclone within 360 nm of the station[1]. The best track and weather observations were then merged into a new data base. From this database, ratios of station reported sustained winds to storm center winds were determined and assigned to a space on a circular grid containing the storm center position. The 360 nm radius circle was divided into 71 equal grid spaces (Figure 2).

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[1]Aviation hourly observations are archived at NCDC for the local times corresponding to 00, 03, 06, 09, 12, 15, 18, 21 GMT only.

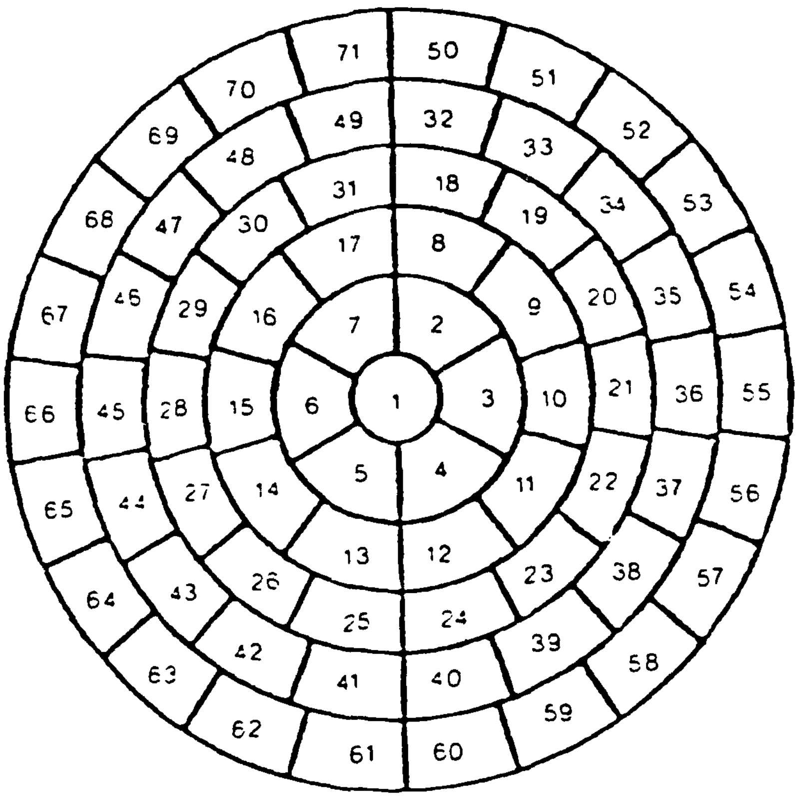

Figure 2. A 360 nm radius circle divided into 71 equal area (5734.5 nm^2) segments which can be centered on the station of interest. The circle is comprised of an inner circle and five surrounding rings. The radial thickness of each ring is approximately 60 nm, but is not a constant. The segments are numbered from the inner circle and spiral outward.

The ratios identified with each area were tabulated and the maximum and mean wind ratios and standard deviations were determined. The ratios are based upon the observed maximum sustained wind speed and the calculated mean sustained wind speed. These are converted to gust ratios by multiplying by a factor of 1.5. The numbers of ratios per area (sample size) were tabulated and cumulative frequency distribution of the ratios computed. Gust ratio plots were subjectively analyzed taking into consideration such factors as sample size for the mean gusts and cumulative frequency distribution for the maximum gusts.

The analyses of the data are presented as isolines which represent the climatological mean or maximum gust to be expected at the station as a percentage of the tropical cyclone center wind. The data base is separated into classification of cyclones, i.e., typhoons and lesser tropical cyclones. The classification is based on the cyclone center wind speed at the time of the station wind observation.

1.1.1.3 Use of the Forecast Aids

The forecast aids can be utilized as follows:

- o locate the actual or forecast tropical cyclone center position on the appropriate forecast aid analysis;
- o determine the maximum (or mean) gust ratio value by interpolating between contours; and
- o apply this ratio (percentage) to the cyclone center wind value to obtain the maximum (or mean) gust values to be used as an aid in making the wind forecast.

For example, if a tropical cyclone has center winds of 100 kt and a ratio of .65 was determined above, then 65% of the center wind gives forecast gusts to 65 kt (.65 x 100 kt) for the station.

Sustained one-minute maximum and average wind values can be found by applying a factor of 2/3 to the gust values. This factor is the inverse of the 1.5 to 1 ratio of gusts to sustained winds that was used in Pettet (1980) and which was substantiated as reasonable by Jarrell and Englebretson (1982a and 1982b).

The contours on the terrain influence maps are percentages derived from the ratios of station winds to tropical cyclone center winds. Several of the maximum contour values are less than 100 percent. The interpretation

of these figures shows that the sites have not experienced winds at the official observation point of as great an intensity as the official typhoon center winds during typhoon passages. While these findings are based on a reasonable sample size, caution should be used in applying these results when a typhoon center is expected to pass over or very near the station. It should be noted that extreme wind measurements are frequently lost because of anemometer failure, hence center grid point data may not adequately reflect worst-case conditions.

Inconsistent results will be obtained from the aids when a tropical cyclone center wind change results in a change of cyclone classification and therefore a change of forecast aid.

The forecast aids are technically valid only for the reporting station at which wind observations were taken. For example, the Sasebo data are valid for the civilian observing station, but not for the Fleet Activities, Sasebo location. However, because the data base available for tropical cyclone studies is small, the grid is fairly coarse. It is doubtful that comparable analyses for other points within the general area would have shown substantially different results. Therefore, unless there are major differences in exposure between sites (e.g., the orientation

and elevation of nearby slopes), the terrain influence maps should provide reasonable estimates of wind gusts over a local area.

1.1.2 CHARM Clocks

1.1.2.1 Wind Probabilities

The consideration of readiness conditions during the approach of a tropical cyclone is largely based on the probable maximum wind at a specified location, but standard forecasts only predict wind speeds within the cyclone itself. It is left to the resources of each individual site to develop an estimate of probable winds at that site--a difficult task. It has been shown that terrain influence maps serve this very purpose. Additionally, the use of wind probability quantifies the threat of 30- and 50-kt wind occurring at a specified location. The wind probabilities used herein and referred as P_{30} and P_{50} are the elapsed time 30- and 50-kt probabilities over the longest available time interval (usually 72 hour). Wind probability is a previously proven concept (Jarrell, 1981). Currently, such probabilities are available for all ocean areas of the world.

It is important not only to set the correct readiness condition but to set it at the proper time. Timing

is critical because most physical preparations cannot be performed in winds greater than 30 kt. Therefore, preparations must be started sufficiently in advance of 30-kt winds to allow for their completion. P_{50} is the determining factor in whether or not to set a readiness condition, but the timing of the condition is dictated by P_{30}. The Cyclone/Hurricane Acceptable Risk Model (CHARM) (see Figure 3 and Jarrell and Brand, 1983) is based on these considerations and best estimates of appropriate cost benefit ratios (CBR)[2] values for each condition. Each combination of P_{30} and P_{50} determines which warning condition (if any) should be set at that time. According to Figure 3, if $P_{30} = .80$ and $P_{50} = .30$, then typhoon condition II should be set. The location of the threshold lines between the conditions is determined by a CBR. Good estimates of CBR's are therefore needed to ensure proper conditions.

1.1.2.2 Selection of CBR Guidelines

Through a comparison of a large number of wind probability forecasts, with hindsight estimates of actual conditions, threshold or guideline CBR's can be related to a confidence level. This means that even though it is virtually impossible to directly estimate these guideline

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[2]Cost-benefit ratio or cost-loss ratio is defined as the cost of preparations divided by the loss which would be avoided by the preparations.

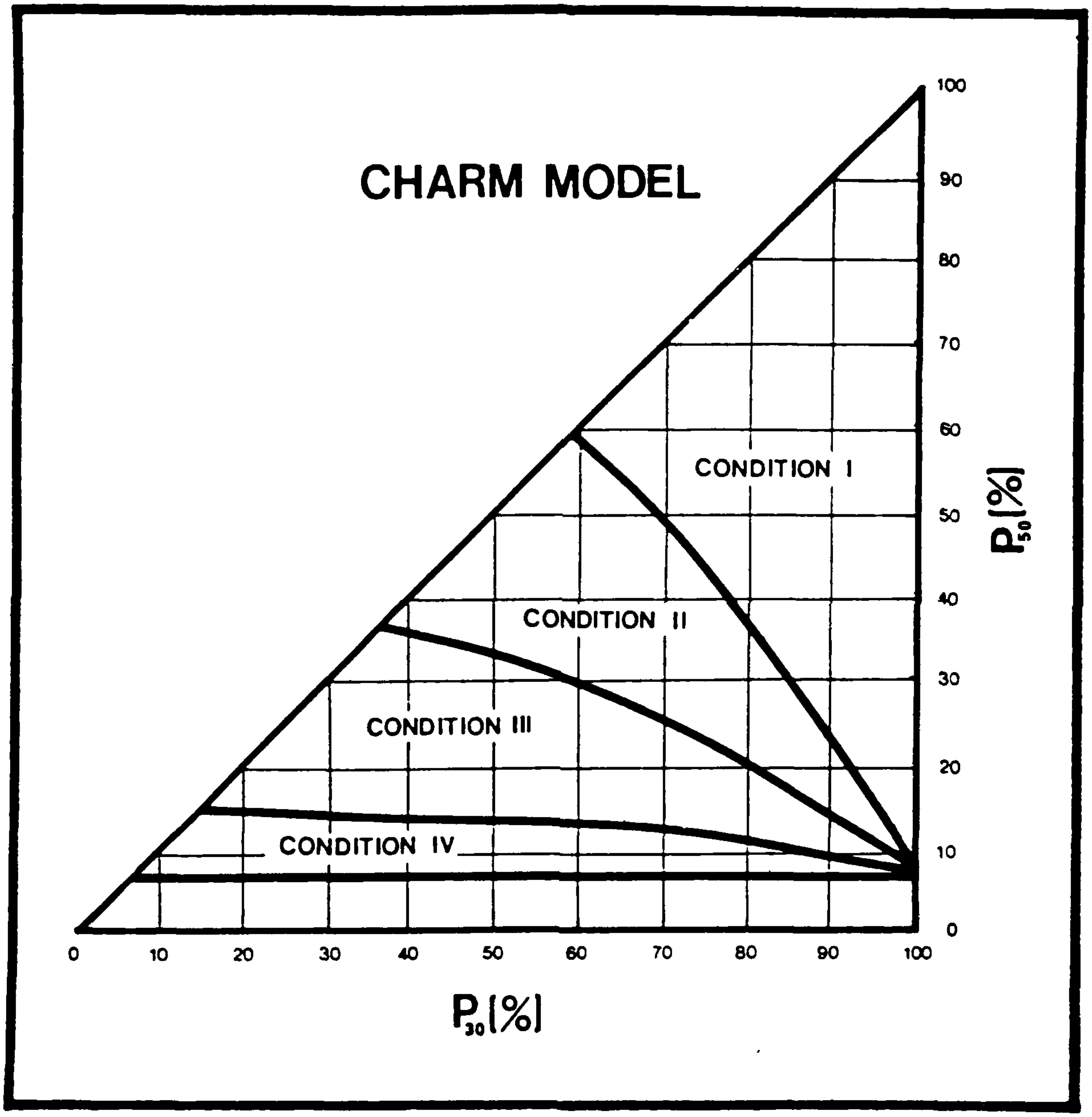

Figure 3. The form of a decision nomograph based on the CHARM model is shown. The actual position of the threshold lines between condition zones is arbitrary.

values, we may still obtain a set of values of known reliability. In fact, the selected degree of reliability, i.e., confidence in percent for each particular condition, determines the guideline CBR values which in turn provide the required confidence levels.

To clarify the meaning of these confidence levels, a 95% (or .95) confidence level for Typhoon Condition I means that Typhoon Condition I would be set in at least 95% of the occasions that warranted it, or correspondingly, that it would not be set on less than 5% of the instances when it should have been set. A 95% Typhoon Condition I confidence level does not mean that typhoon force winds occur within 12 hours in 95% of the occasions that the condition is set. It must be noted that higher confidence levels necessarily result in higher overwarning rates, a fact which explains why it is unrealistic to expect 100% confidence levels.

The technical selection of CBR thresholds is discussed by Jarrell (1986) and will not be repeated here.

1.1.2.3 Use of CHARM Clock

Figure 4 is a CHARM Clock for worst case (5%) arrival time of typhoon force winds. To use the CHARM clock, enter with the largest values of 30- and 50-kt wind probabilities. These are the elapsed time values usually over a 72-hour period. They are found as the far right two digits in the appropriate lines for your station in the tropical cyclone wind probability message. Read off the worst case arrival time for the specified wind force. Figure 5 illustrates the use of these diagrams for a hypothetical situation. This illustration results in a worst case lead time of 42 hours meaning the time to set condition III may be at hand--if condition III is not already in effect. Any action which requires 42 hours and must be completed should be started. Since these time estimates are worst case they purposely underestimate the remaining lead time in all but the worst case. For this reason one should not feel compelled to rush in setting condition III when the CHARM clock indicates that there may be as little as 48-hour lead time to destructive winds. Rather this should be viewed as a necessary condition prior to setting a condition, but <u>not</u> a sufficient reason for setting it. The prudent commanding officer <u>should consider</u> setting the indicated condition but he will often delay it. As a median, these worst case lead times will underestimate the actual lead time by about 12

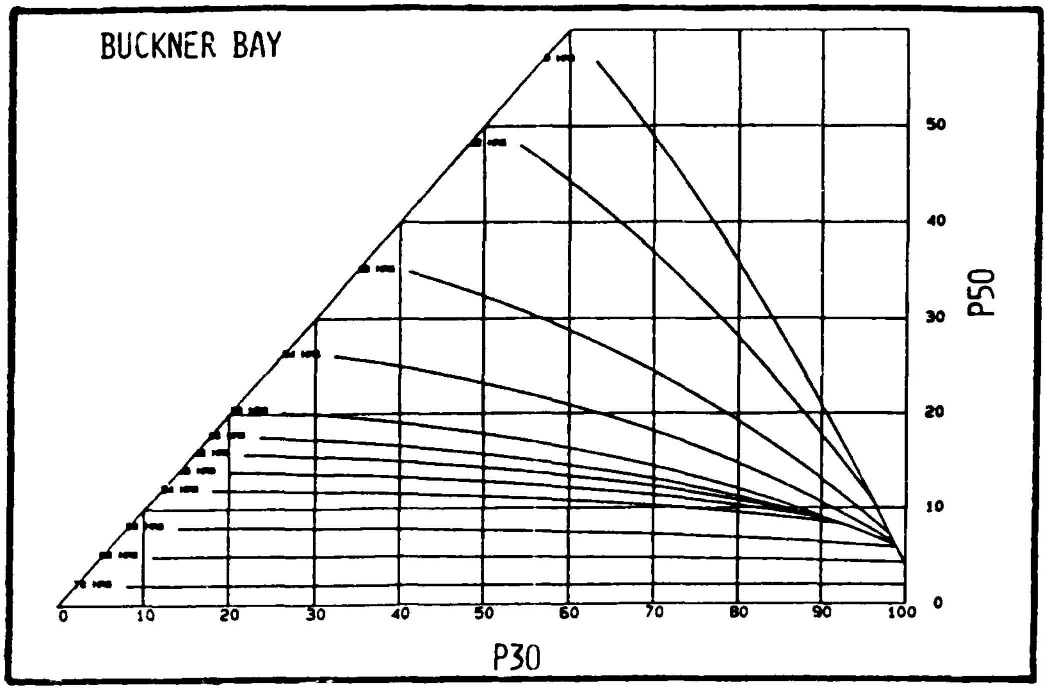

Figure 4. CHARM clock representation for typhoon force winds at Buckner Bay, Okinawa. Time lines represent worst case (5%) arrival time of typhoon force winds. P30 and P50 are elapsed time 30- and 50-kt wind probabilities.

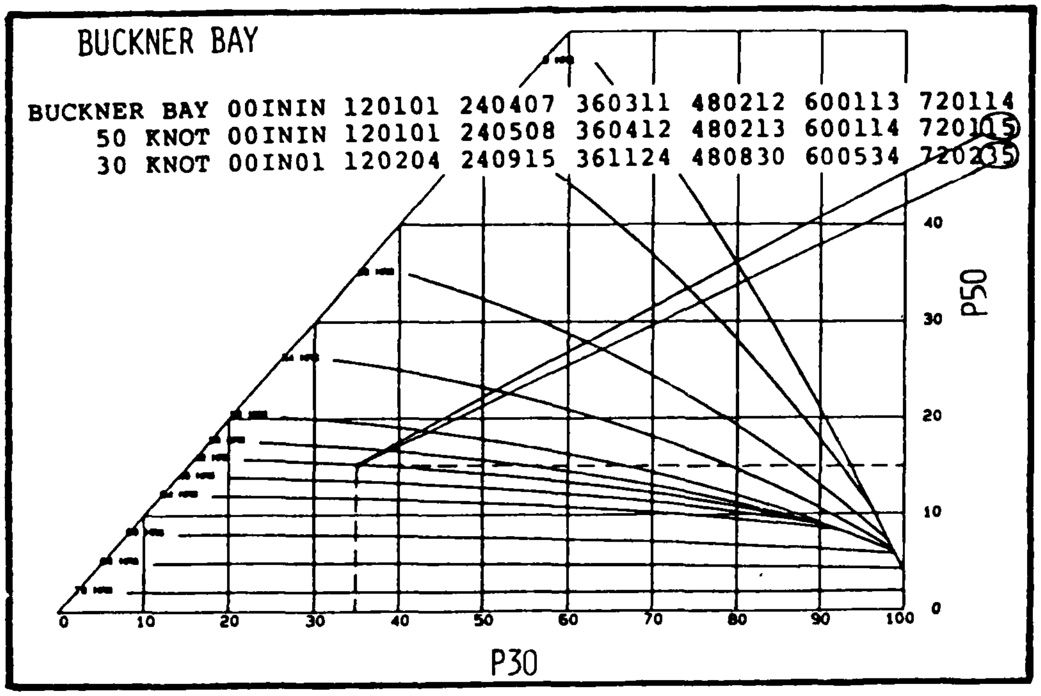

Figure 5. Same diagram as figure 4 except superimposed is a hypothetical wind probability message. Circled numbers are the 30- and 50-kt elapsed time wind probabilities. The result can be read as "in the worst case, typhoon force winds can arrive within 42 hours".

hours and as much as 18 hours at the end of the time scale (72 hours). By using up half of that cushion one can usually avoid setting conditions in the nighttime hours when their effectiveness is marginal. Notwithstanding the preceding, to be 95% certain of having the required action hours in each condition, one must allow for the worst case. Thus it is not prudent to routinely use up the cushion unless the allowed lead time is not needed because of some existing special circumstances.

SECTION 2

SASEBO, JAPAN

2.1 Discussion of Harbor Exposure

The following summary description by Brand and Blelloch (1976) sums up the salient facts about the harbor:

> "The conclusion reached by this study is that Sasebo Harbor is a favorable typhoon haven for all ships except aircraft carriers. This conclusion is based on the following reasons:
>
> - o The harbor topography provides excellent protection from winds out of the north or east and good protection from southerly wind. However, due to the large "sail area" of a carrier, winds may affect the ship severely.
> - o The anchor holding capability in the typhoon anchorage is excellent.
> - o There is sufficient maneuvering room at typhoon anchorages in the outer harbor. However, aircraft carriers may be too restricted if many ships are present.
> - o The inner harbor provides little protection for aircraft carriers. Ships of the size of AR's, AOE's, and AF's can find good protection at India Basin, Berths 8 and 9. Small ships have excellent protection in wet drydocks.
> - o Surge effect is, in most cases, minimal and wave action in the past has not been too severe during the passage of a typhoon.
> - o Port services available are excellent."

We have concluded from the above that evacuation is unnecessary, but that for winds of 50-kt in the vicinity, ships would need to be repositioned to the most suitable berthing depending on size and condition. We have therefore designed the "CHARM CLOCK" decision aid for 50kt winds.

2.2 Discussion of Data Sets

Observations collected from the vicinity of Sasebo (within 0.6° lat/long) out of the FNOC archives totalled over 26,000 from months when TC's were known to have passed. Of these only 11% were from Sasebo, 46% were from Nagasaki, 16% from Saga and 12% from Matsuura. About 3% were from ships in the area and the remaining 12% were sporadic from occasionally reporting or once per day stations.

Regression equations to predict two components of Sasebo's winds were written on the winds of 7 stations plus ships plus miscellaneous reports and for up to 8 directions. There were potentially 144 equations; however, insufficient observations from several direction-station combinations restricted the actual number to under 100. These were developed on the 0900I (0000GMT) observations partly to avoid land/sea breeze effects, but also because Sasebo is a day-light station and only 0900 and 1500I observations were routinely available.

When the equations were applied there was often more than one equation to estimate the wind at Sasebo. Unless there was an actual observation, the various estimates for Sasebo winds were combined by weighting by the reciprocal of the unexplained variance from the regression equation. In this manner a fairly solid record of Sasebo psuedo-observations was compiled for the years 1971-85 to combine with those received from NCDC Asheville from 1973-1985. For the most part, these actual observations were daylight hours at 1-3 hour intervals and these were adjusted in accordance with Appendix A to estimate the maximum winds.

2.3 Results

Tropical cyclones passing Sasebo are generally beyond their peak strength and just beginning to weaken. Frequently this weakening process will involve an influx of cold air and transitioning into a mid-latitude or extra-tropical cyclone. In either case these storms are extremely dangerous; thus the excellent protection afforded in the Sasebo harbor is most valuable. Terrain protection is manifest in Figures 6 through 9 where mean wind gusts in the worst case have been on the order of only 50-60% of the typhoon maximum. Because of the terrain protection and a climatological tendency for tropical cyclones to be weakening, wind probabilities at Sasebo are significantly

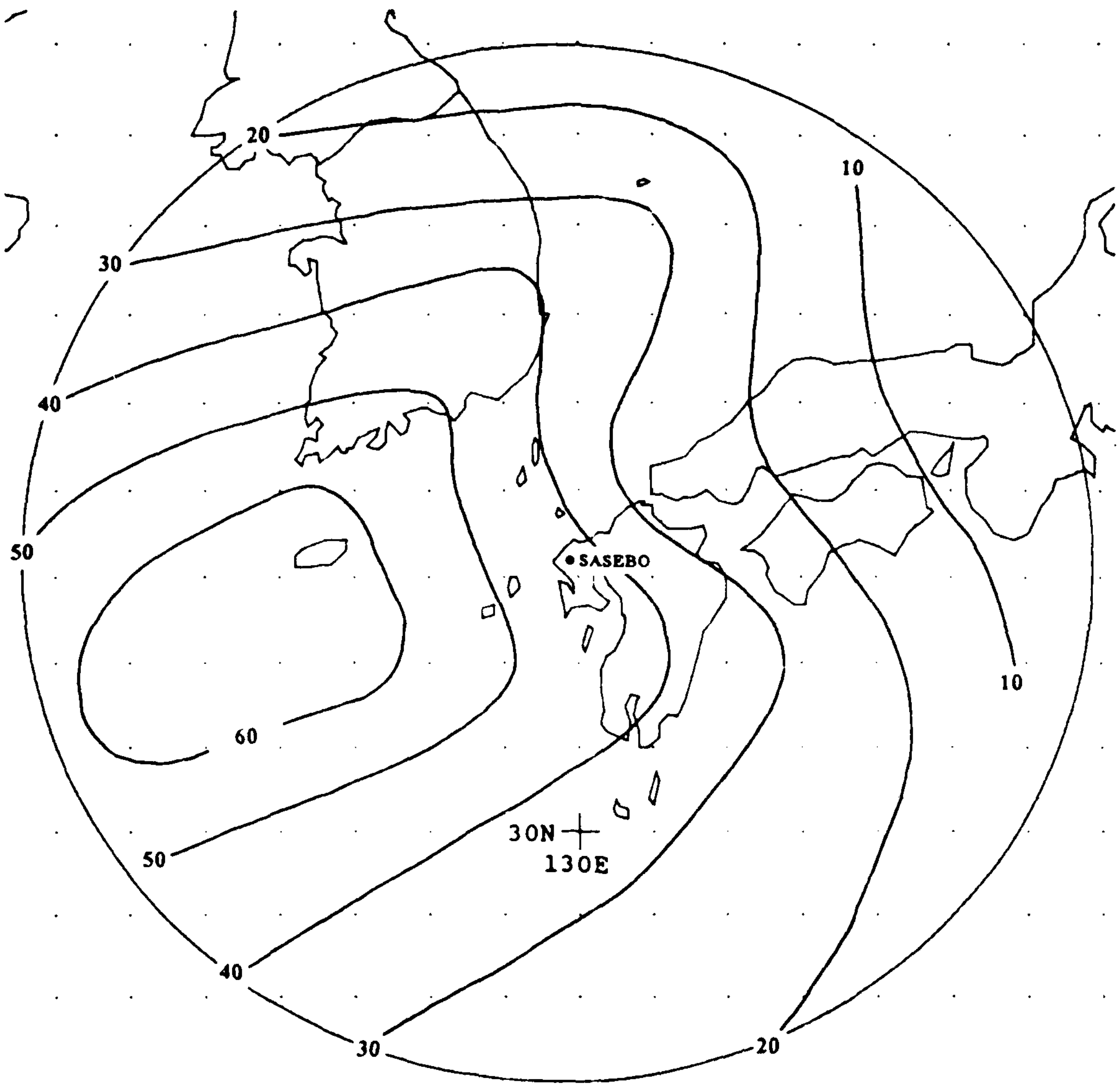

Figure 6. Mean Gust Ratios (labelled as percentage) for Sasebo when a tropical cyclone of less than typhoon strength (<64 kt) is centered within 360 nm of the station. Locate the tropical cyclone center by latitude and longitude and interpolate the ratio (percentage) value. Multiply the tropical cyclone center wind speed by this percentage to get the wind speed value of the maximum gust expected with the given center position and wind speed. Multiply the mean gust speed by 0.67 to find the mean one-minute average sustained wind speed.

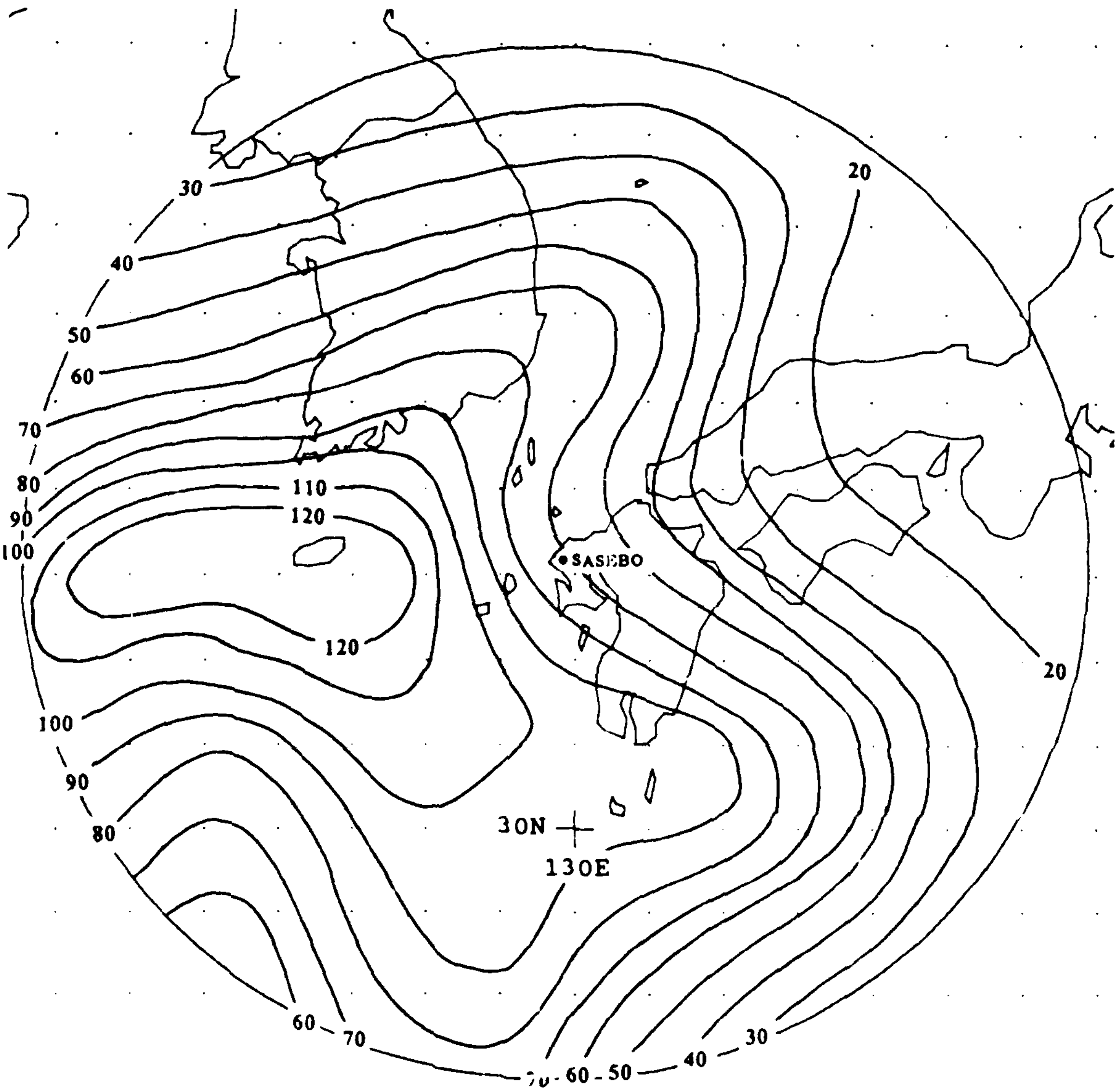

Figure 7. Maximum Gust Ratios (labelled as percentage) for Sasebo when a tropical cyclone of less than typhoon strength (<64 kt) is centered within 360 nm of the station. Locate the tropical cyclone center by latitude and longitude and interpolate the ratio (percentage) value. Multiply the tropical cyclone center wind speed by this percentage to get the wind speed value of the maximum gust expected with the given center position and wind speed. Multiply the maximum gust speed by 0.67 to find the maximum one-minute average sustained wind speed.

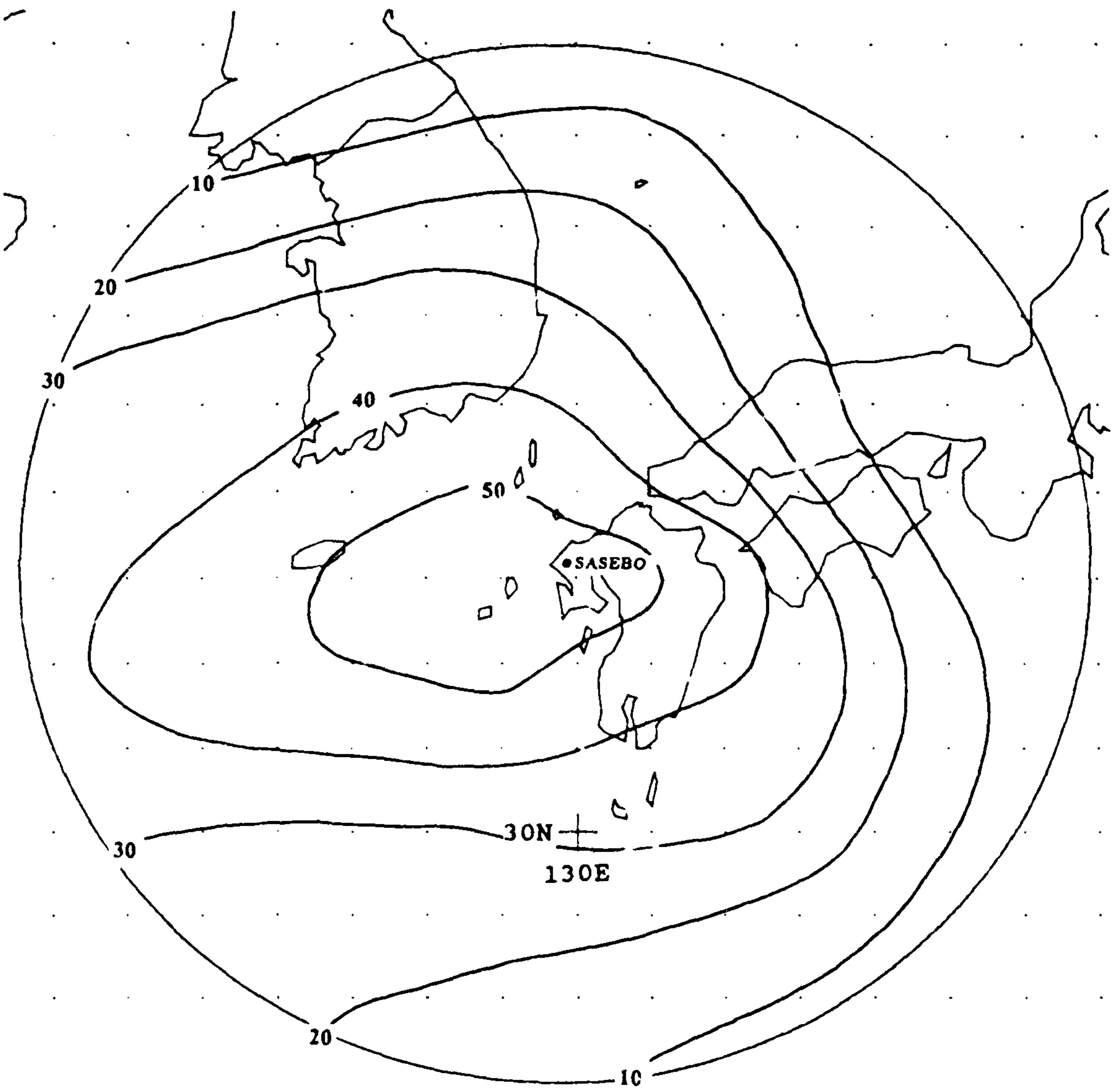

Figure 8. Mean Gust Radios (labelled as percentage) for Sasebo when a tropical cyclone of typhoon strength (≥ 64 kt) is centered within 360 nm of the station. Locate the typhoon center by latitude and longitude and interpolate the ratio (percentage) value. Multiply the typhoon center wind speed by this percentage to get the wind speed value of the mean gust expected with the given center position and wind speed. Multiply the mean gust speed by 0.67 to find the mean one-minute average sustained wind speed.

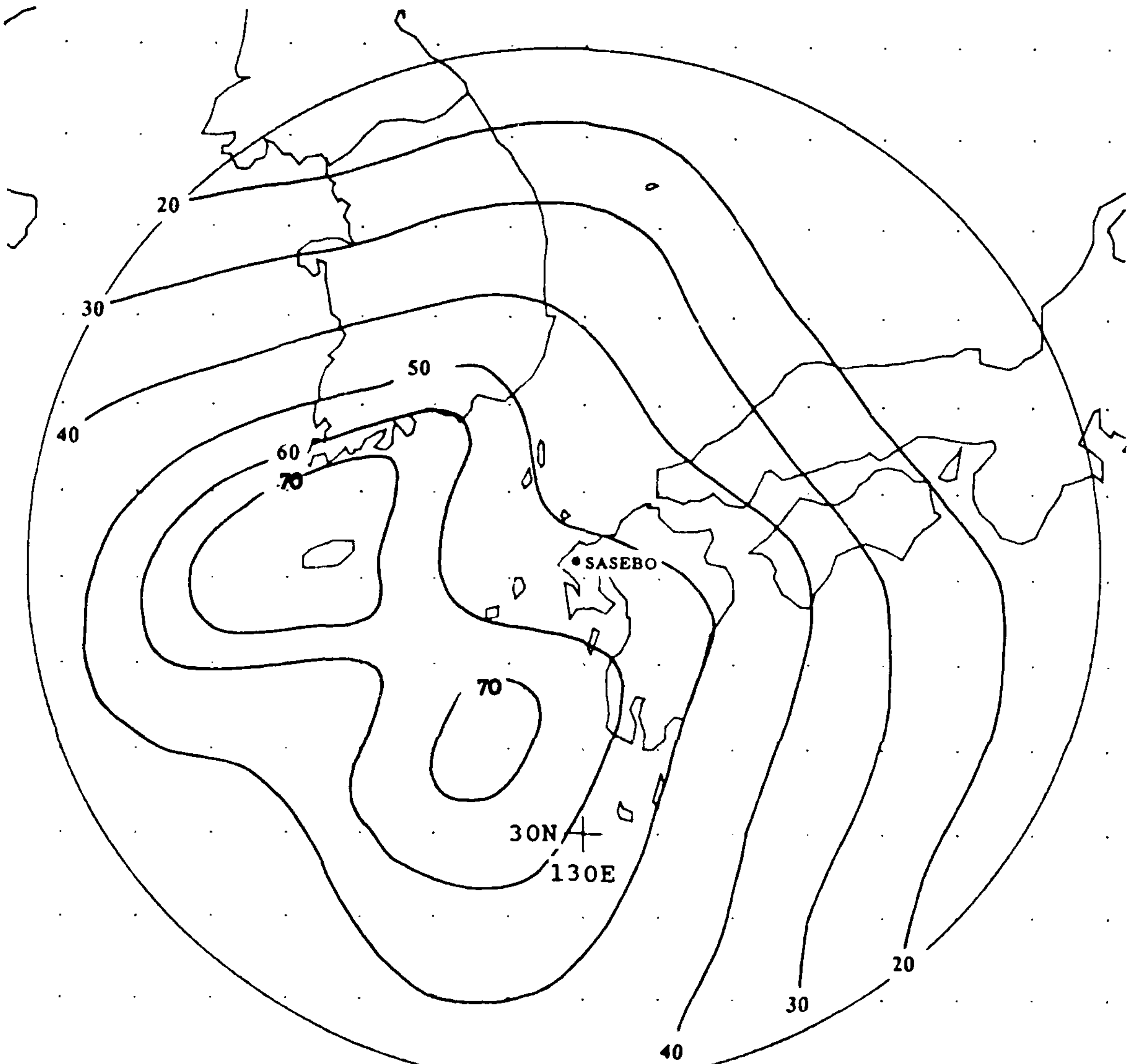

Figure 9. Maximum Gust Ratios (labelled as percentage) for Agana when a tropical cyclone of typhoon strength ($\geq$64 kt) is centered within 360 nm of the station. Locate the typhoon center by latitude and longitude and interpolate the ratio (percentage) value. Multiply the typhoon center wind speed by this percentage to get the wind speed value of the maximum gust expected with the given center position and wind speed. Multiply the maximum gust speed by 0.67 to find the maximum one-minute average sustained wind speed.

lower than they would be either over adjacent water or over rough terrain farther south. The CHARM CLOCK shown in Figure 10 is for the 5% worst case (earliest arrival) of 50-kt winds. This is intended to serve as a guide to general tropical cyclone condition setting on the naval base and specifically within the harbor.

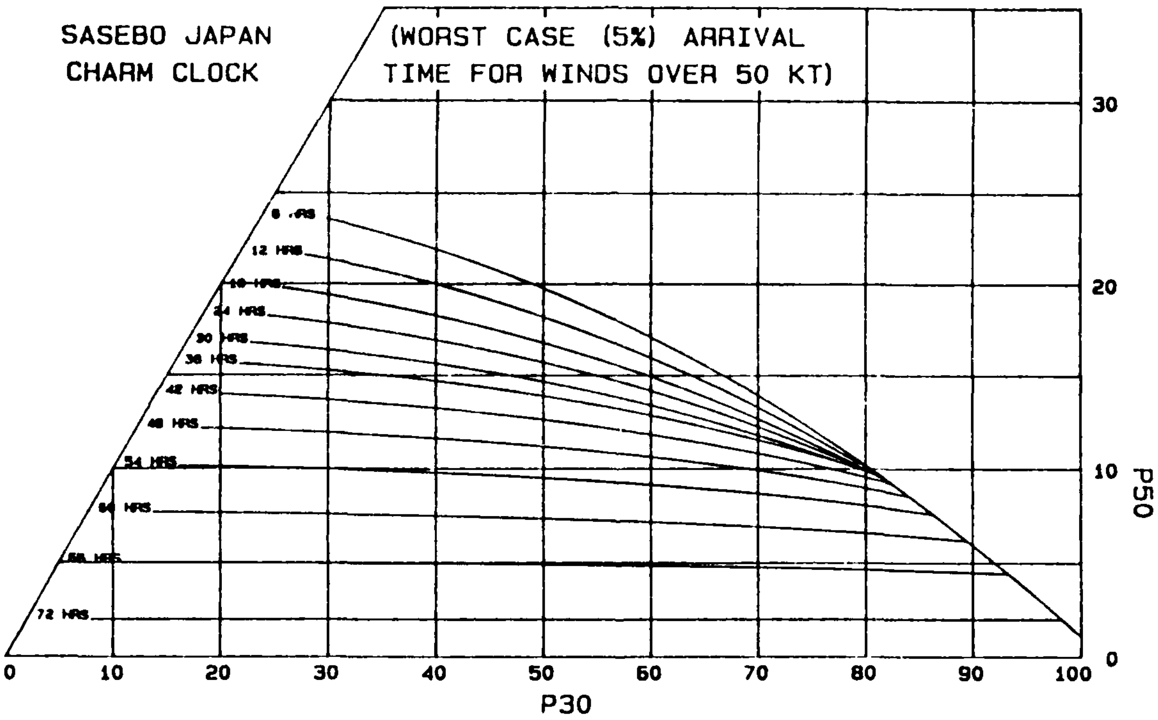

Figure 10. Sasebo CHARM clock for worst case (5%) arrival time of 50-kt (or greater) winds.

Table 1.

Overwarning rates for occasions where 50-kt tropical cyclone conditions would have been recommended

50-kt TC Condition

ACTUAL	I	II	III	IV
>63 kt	9.2	18.2	51.6	332
≥50 kt	1.3	1.5	2.4	9.0

For example, to put the overwarning rate in perspective, if an action is ordered on 50-kt tropical cyclone condition II, it would be ordered unnecessarily between one and two times (1.5 in Table 1) for each time it was (in hindsight) necessary. The extremely high overwarning rates for typhoon force winds is indicative of the rarity of typhoon force winds and the excellent nature of the terrain protection.

2.4 Overwarning

Table 1 shows overwarning rates for events in the simulated data set when various 50-kt tropical cyclone conditions would have been set on the basis of exceeded threshold values. Thus the use of TCCSA (Tropical Cyclone

Condition Setting Aid) for 50-kt tropical cyclone conditions I through IV results in excellent rates of 1.3, 1.5, 2.4 and 9.0, respectively.

SECTION 3

IWAKUNI, JAPAN

3.1 Discussion of Harbor Exposure

The following extract from Brand and Blelloch (1976) points out favorable sheltering aspects of Iwakuni and vicinity.

> "The mountainous terrain of the islands of Honshu, Kyushu, and Shikoku, with elevations exceeding 3000 ft., would lead one to expect that the winds of a tropical cyclone would be greatly reduced before reaching the Hiroshima Bay region. This is, in fact, the case when storms pass either to the west or the east of the bay region.
>
> When storms pass to the west, the wind will normally be reduced 35-50% while storms passing to the east will usually have their winds reduced approximately 60%. Also it appears that southerly winds coming through the Bongo Straits and Inland Sea have the path of least resistance into the Hiroshima Bay area. Generally this would be the case when a storm passes to the west."

Brand and Blelloch stop short of recommending Iwakuni as a typhoon haven, but they do recommend the nearby Port of Kure and area typhoon anchorages. We have surmised that the expectation of 50-kt winds should be sufficient to warrant evacuation of seaworthy vessels from Iwakuni.

3.2 Discussion of Data Sets

Observations were obtained from NCC Asheville, NC for the period 1955-85. These were adjusted according to the methodology described in Appendix A. After adjustment there were 10 tropical cyclones estimated to have caused at least 50-kt sustained winds at Iwakuni. These are listed in Table 2.

Table 2

Tropical cyclones estimated to have caused at least 50-kt winds at Iwakuni.

Storm	Month	Year	Storm	Month	Year
BABS	AUG	56	ANITA	AUG	70
SARAH	SEP	59	OLIVE	AUG	71
BESS	AUG	63	KEN	SEP	82
JEAN	AUG	65	HOLLY	AUG	84
WILDA	AUG	70	PAT	AUG	85

3.3 Results

As with Sasebo, tropical cyclones passing Iwakuni are generally beyond their peak strength and just beginning to weaken. Frequently this weakening process involves an influx of cold air and the transitioning into a mid-latitude or extratropical cyclone. In either case the storms can be extremely dangerous; thus evacuation of Iwakuni can be readily justified. Terrain protection can be inferred from Figures 11 through 14. As seen from Figures 12 and 14, when

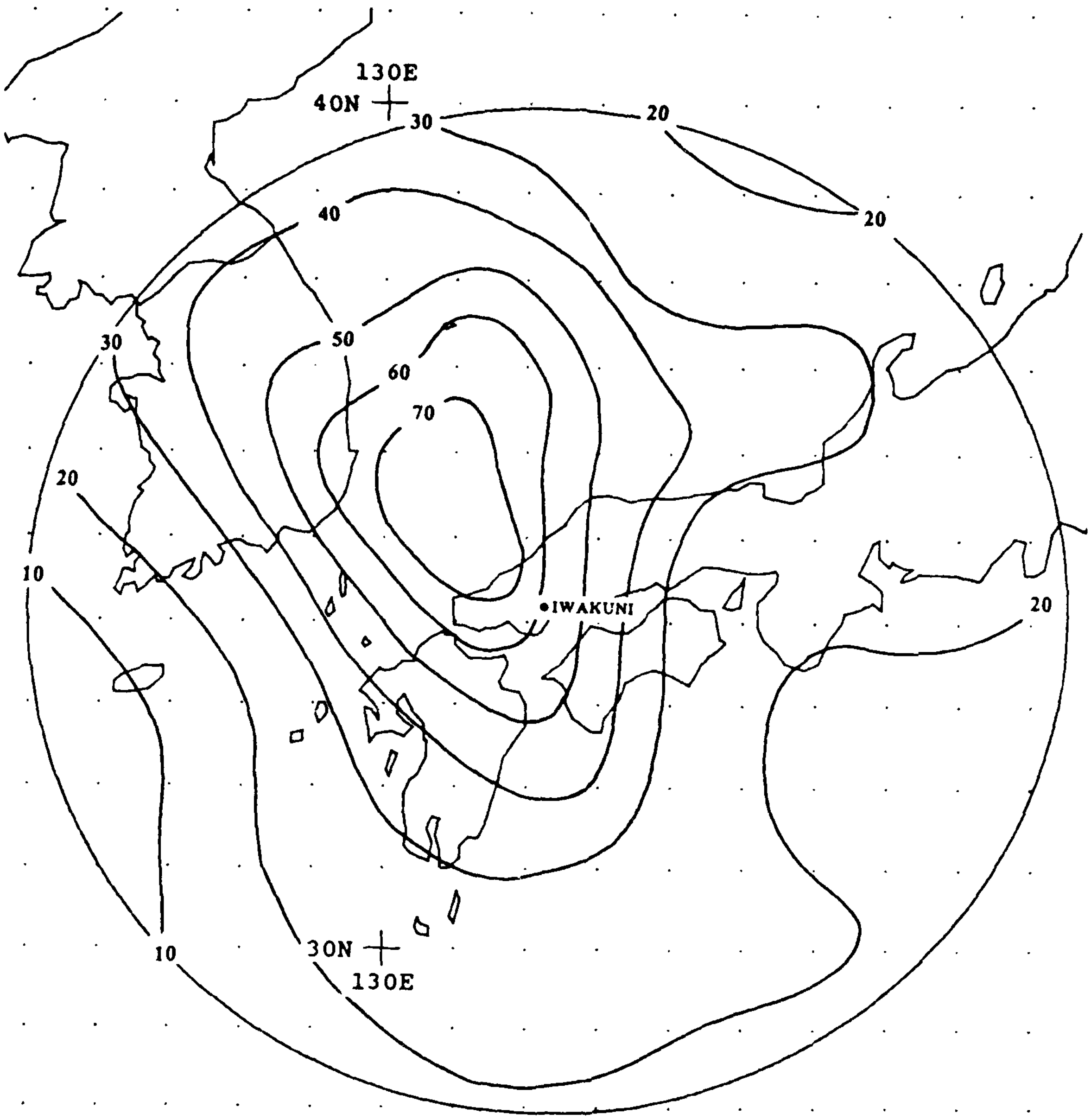

Figure 11. Mean Gust Ratios (labelled as percentage for Iwakuni when a tropical cyclone of less than typhoon strength (<64 kt) is centered within 360 nm of the station. Locate the tropical cyclone center by latitude and longitude and interpolate the ratio (percentage) value. Multiply the tropical cyclone center wind speed by this percentage to get the wind speed value of the maximum gust expected with the given center position and wind speed. Multiply the mean gust speed by 0.67 to find the mean one-minute average sustained wind speed.

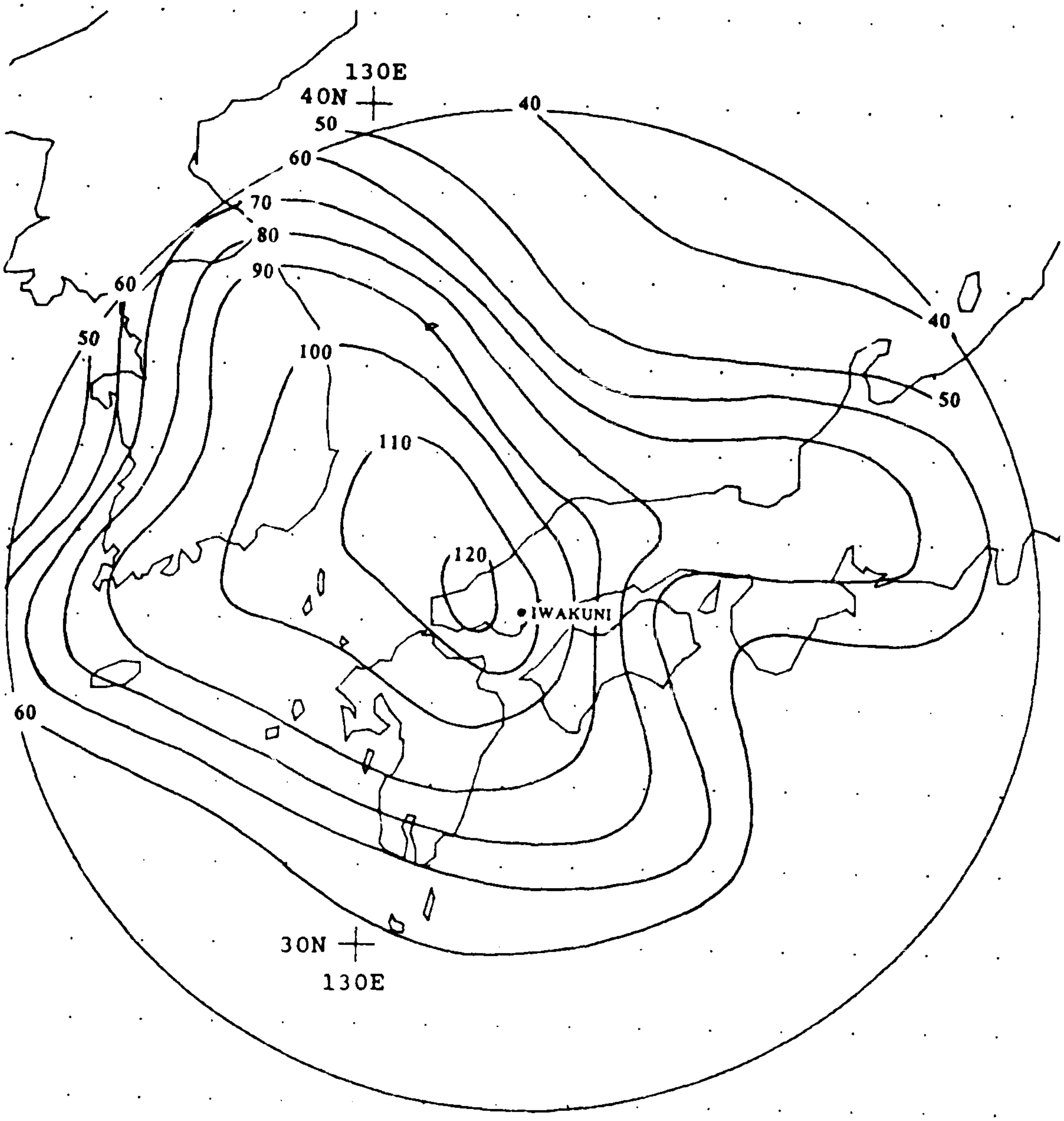

Figure 12. Maximum Gust Ratios (labelled as percentage) for Iwakuni when a tropical cyclone of less than typhoon strength (<64 kt) is centered within 360 nm of the station. Locate the tropical cyclone center by latitude and longitude and interpolate the ratio (percentage) value. Multiply the tropical cyclone center wind speed by this percentage to get the wind speed value of the maximum gust expected with the given center position and wind speed. Multiply the maximum gust speed by 0.67 to find the maximum one-minute average sustained wind speed.

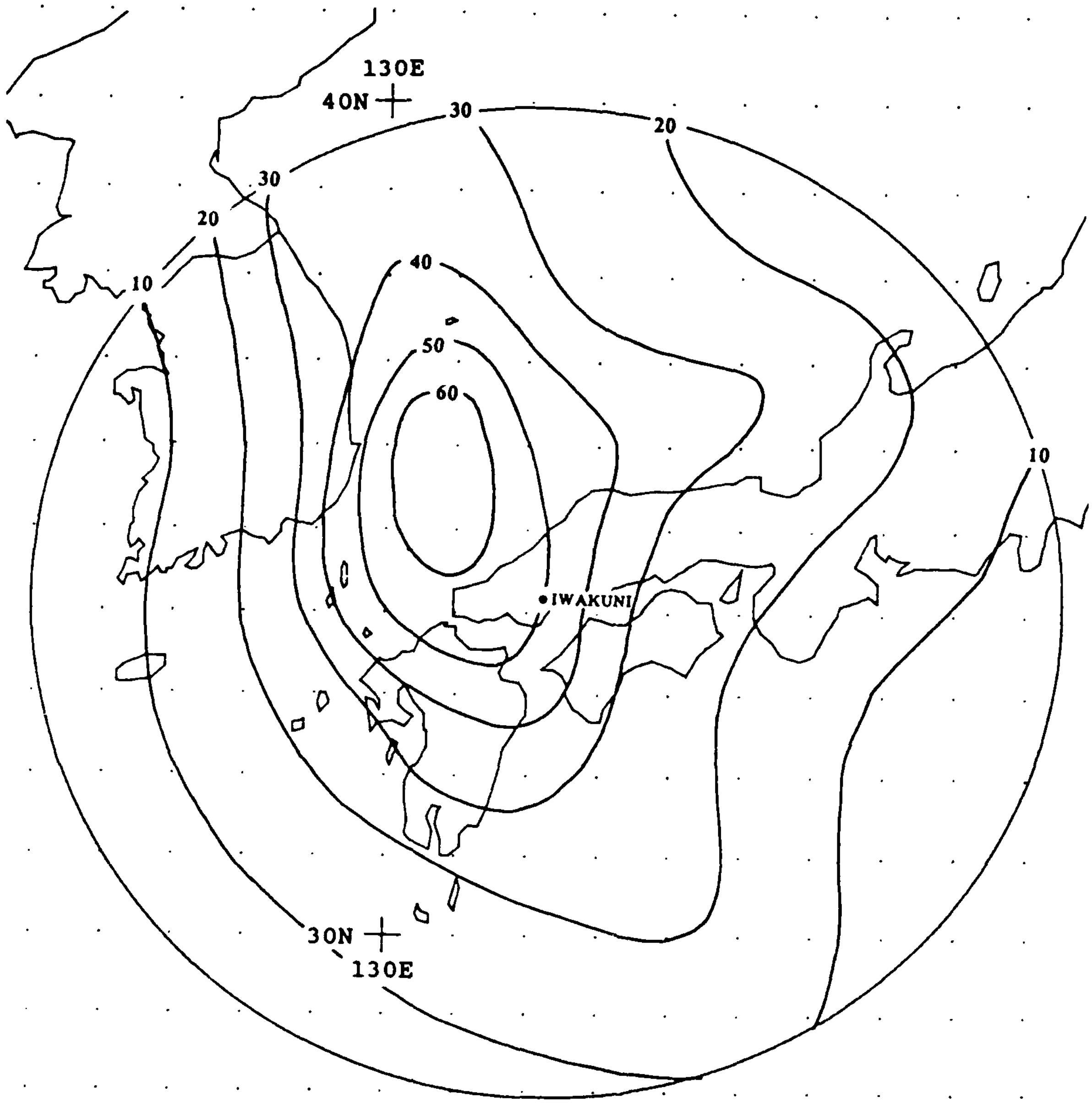

Figure 13. Mean Gust Ratios (labelled as percentage) for Iwakuni when a tropical cyclone of typhoon strength ($\geq$64 kt) is centered within 360 nm of the station. Locate the typhoon center by latitude and longitude and interpolate the ratio (percentage) value. Multiply the typhoon center wind speed by this percentage to get the wind speed value of the maximum gust expected with the given center position and wind speed. Multiply the maximum gust speed by 0.67 to find the maximum one-minute average sustained wind speed.

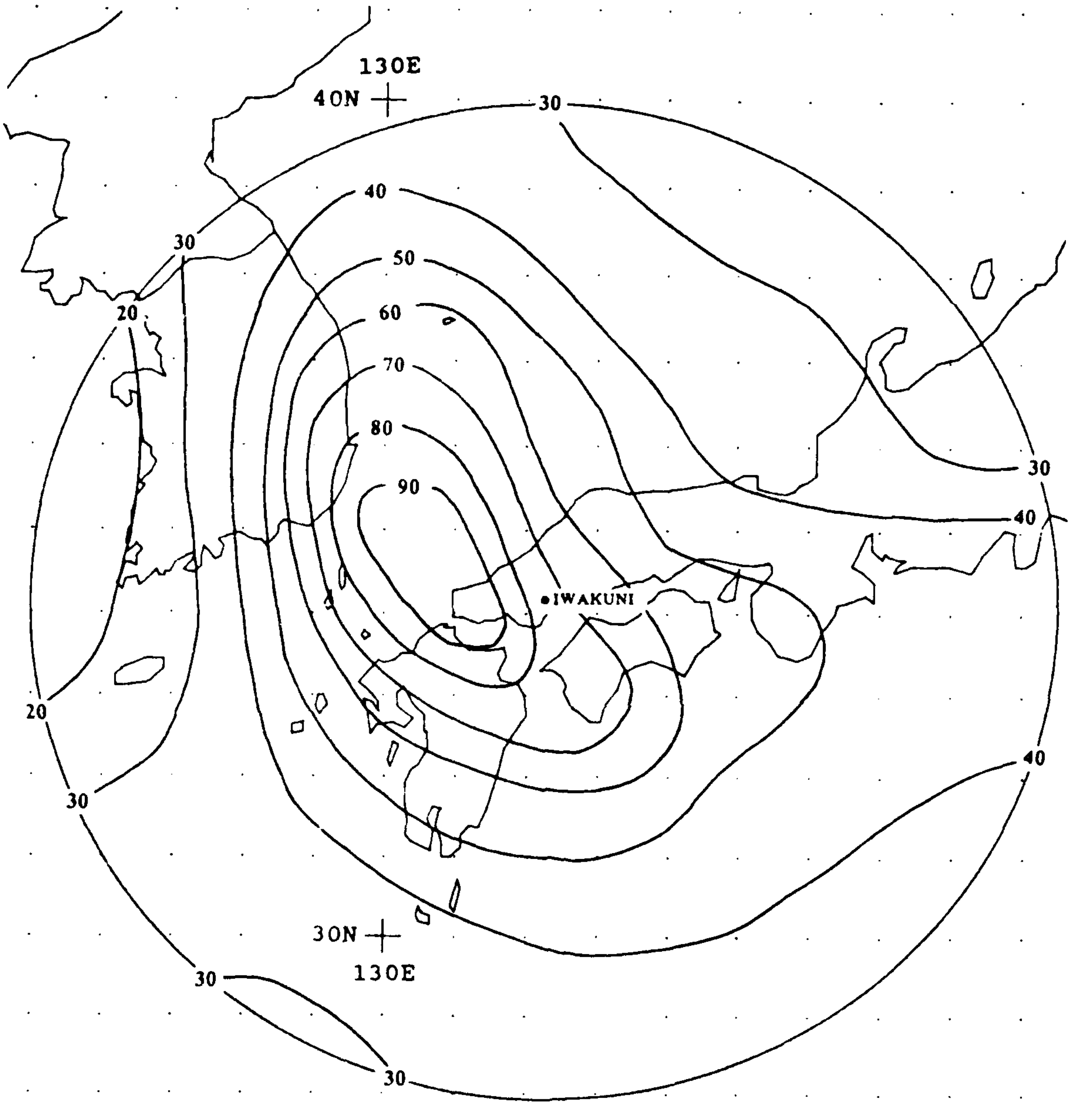

Figure 14. Maximum Gust Ratios (labelled as percentage) for Iwakuni when a tropical cyclone of typhoon strength (≥64 kt) is centered within 360 nm of the station. Locate the typhoon center by latitude and longitude and interpolate the ratio (percentage) value. Multiply the typhoon center wind speed by this percentage to get the wind speed value of the maximum gust expected with the given center position and wind speed. Multiply the maximum gust speed by 0.67 to find the maximum one-minute average sustained wind speed.

compared to figures 7 and 9, protection, though good, is somewhat less than for Sasebo. Because terrain protection is less than at Sasebo, wind probabilities will, on the average, be higher at Iwakuni. The CHARM CLOCK shown in Figure 15 is for the 5% worst case (earliest arrival) of 50-kt winds. This is intended to serve as a guide to tropical cyclone condition setting any accompanying sortie from the harbor or fly-away of aircraft.

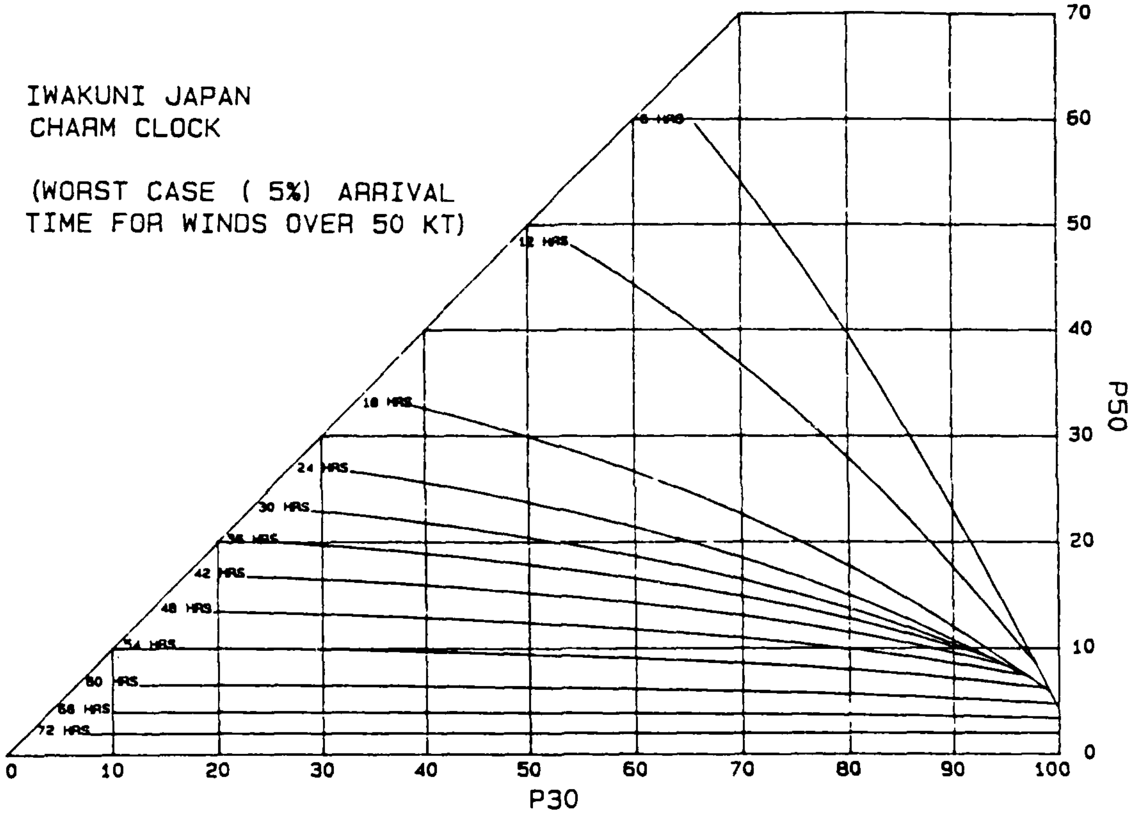

Figure 15. Iwakuni CHARM clock for worst case (5%) arrival time of 50-kt (or greater) winds.

3.4 Overwarning

Table 3 shows overwarning rates for events in the simulated data set when 50-kt tropical cyclone conditions would have been set on the basis of the above CHARM CLOCK. Thus the use of TCCSA for 50-kt tropical cyclone condition I

through III will result in satisfactory overwarning rates of 1.4, 8.1, and 12.9 respectively. The overwarning rate of 142 for condition IV is not considered usable.

Table 3

Overwarning rates for occasions where 50-kt tropical cyclone conditions would have been set at Iwakuni.

TROPICAL CYCLONE CONDITION

	I	II	III	IV
≥ 64 kt	2.3	13.9	31.3	500
≥ 50 kt	1.4	8.1	12.9	142

For example, in order to put overwarning rates in perspective, of the cases where tropical cyclone condition II is set based on the CHARM clock, winds in excess of 50-kt will be observed once for every eight times lesser winds occur. However, in about half of those eight cases, winds of at least gale force (>33 kt) will be observed. From this perspective, the overwarning rates appear to be reasonable except for that of conditon IV.

SECTION 4

SUMMARY

The development of both terrain influence maps and CHARM clocks was successful for Sasebo and Iwakuni, Japan. The only major problem area involved an inadequate archive of suitable wind observational data, particularly at Sasebo. This limitation was overcome by two innovations augmenting the available data. There were:

a. By developing relationships between Sasebo winds and those of other nearby stations, missing Sasebo winds could be estimated from neighboring reports.

b. Generalized statistical relationships were developed to estimate maximum wind observations from mean winds observed at one- or three-hourly intervals.

Using techniques such as these can make possible the development of climatology-based decision aids in areas where either the period of record is short or the frequency of passing tropical cyclones is small (e.g., Atlantic coast).

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APPENDIX A

STATISTICAL ADJUSTMENT OF OBSERVED WINDS

In the terrain wind studies there is a requirement to know both the peak gust and the maximum sustained winds. Here sustained wind is a one minute average. The use of aviation hourly observations with the daily summary provides both these values. Frequently, however, the special, off time, observations (which usually contain both the maximum sustained wind and peak gusts) are not archived. In the case of Iwakuni, only hourly observations were available and there was a several-year period with only three hourly observations. Data for Sasebo was sporadic, having been archived off the operational weather collectives, and it was typically at three or six hour intervals.

A problem arises when a sample wind is taken only on the hour since that sample will rarely represent the maximum sustained wind. Since one-minute averages are being considered (as sustained), there were 60 such averages in each hour and we only have one of them. We do, however, know something about the statistical distribution of winds. Winds are usually considered to follow a Rayleigh distribution $P(V > x) = e^{-x^2/2\sigma^2}$ (Surry and Davenport, 1980), where V is the wind speed, x is an independent variable, σ is the standard deviation of the wind speeds. We do not know σ; however in a Rayleigh distribution $\sigma = .7979\ \bar{V}$ where

$\bar{V}$ is the mean wind speed. We can estimate $\bar{V}$ with V which in turn provides an estimate of σ.

Now if we view each one-minute average as being made up of 60 one-second readings then we know (according to the mean value theorem) that these one-minute means are approximately normally distributed with mean = V and $S = \sigma/\sqrt{60}$. Therefore we would expect the minimum of these to be at the 1/60 point in the low tail of the distribution and the maximum to be at 1/60 in the high tail or 2.13 S from the mean.

$$V_{max} = V + 2.13\ S = V + 2.13 \times \sigma/\sqrt{60}$$
$$= V(1 + .7979 \times 2.13/\sqrt{60}) = 1.22\ V$$

Similarly the maximum from 3 hourly observations can be estimated by 1.26 V.

The implicit assumption is that the wind regime stays constant throughout the time interval which is doubtful for 3 hours during a tropical cyclone passage, but this correction is in the right direction.

Peak gusts have been shown to be fairly well estimated by taking 140-150% of the maximum one minute average wind. In these studies we have consistently used 150% of the estimated maximum sustained wind.

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